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DRAG AND PERFORMANCE CHARACTERISTICS OF FLEXIBLE AERODYNAMIC DECELERATORS IN THE WAKES OF DOUBLE-STRUT MOUNTED FOREBODIES AT MACH NUMBERS FROM 2 TO 5

A. W. Myers

ARO, Inc.

December 1967

VON KÁRMÁN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

DRAG AND PERFORMANCE CHARACTERISTICS OF
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Dtd 20 Dec, 74

FOREWORD

The work reported herein was done at the request of the Air Force Flight Dynamics Laboratory (AFFDL) (FDFR), Air Force Systems Command (AFSC), for the Goodyear Aerospace Corporation, Akron, Ohio, under Program Element 6240533F, Project 6065, Task 606507.

The results of tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The tests were conducted from September 12 to 16, 1967, under ARO Project No. VT0626, and the manuscript was submitted for publication on November 6, 1967.

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This technical report has been reviewed and is approved.

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ABSTRACT

Tests were conducted in the 40-in. supersonic tunnel of the von Kármán Gas Dynamics Facility to determine the drag and stability characteristics of a series of flexible supersonic decelerator models deployed at various positions aft of two double-strut mounted forebodies and to define the centerline wake flow characteristics of one of the forebodies. Data were obtained at Mach numbers from 2 to 5 at dynamic pressures corresponding to pressure altitudes which ranged from 82,000 to 142,000 ft. Selected typical results are presented.

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TABLE

APPENDIX
Illustrations

NOMENCLATURE

a, b, c	Parachute canopy grid dimensions, in.
C_{D_P}	Drag coefficient of parachute canopy based on projected canopy area, drag force/$q_\infty S_p$
D_i	Parachute canopy inlet diameter, in.
D_p	Parachute canopy projected diameter, in.
D_r	Parachute canopy roof cap diameter, in.
d	Forebody base diameter, in.
f	Parachute canopy reinforcement web thickness, in.
ℓ	Parachute canopy skirt length, in.
ℓ_s	Parachute suspension line length, in.
M_L	Wake local Mach number
M_∞	Free-stream Mach number
m	Canopy surface dimension, in.
q_L	Wake local dynamic pressure, psia
q_∞	Free-stream dynamic pressure, psia
S_p	Design projected area of inflated parachute canopy, in.
v, w	Parachute suspension line cross-sectional dimensions, in.
x	Distance from the base of the forebody model to the parachute canopy inlet, in.
λ_t	Total parachute canopy porosity, percent

SECTION I
INTRODUCTION

Tests were conducted in the 40-in. supersonic tunnel (Gas Dynamic Wind Tunnel, Supersonic (A)) of the von Kármán Gas Dynamics Facility (VKF) to verify, through the use of an improved drag measuring system, the drag and stability characteristics reported by Myers and Hahn[1] for a series of flexible supersonic decelerator models at various positions aft of two double-strut mounted forebodies and to determine the centerline wake flow characteristics of one of the forebodies. The two forebodies were the Arapaho "C" test vehicle and a blunted elliptical cone model, and the decelerators were "Parasonics", members of the hyperflo family of high performance, supersonic parachutes. The tests were conducted at Mach numbers from 2 to 5 at dynamic pressures corresponding to pressure altitudes which ranged from 82,000 to 142,000 ft.

Selected typical results are presented showing the centerline wake characteristics of the Arapaho "C" forebody model and the effects of Mach number, location in the wake, and design parameters on the parachute drag. The parachute performance and stability (stability as discussed in this report refers only to the conditions of oscillatory motion of the parachute with respect to the forebody) are summarized for each test condition.

SECTION II
APPARATUS

2.1 WIND TUNNEL

Tunnel A is a continuous, closed-circuit, variable density wind tunnel with an automatically driven, flexible-plate-type nozzle and a 40- by 40-in. test section. The tunnel operates at Mach numbers from 1.5 to 6 at maximum stagnation pressures from 29 to 200 psia, respectively, and stagnation temperatures up to 300°F ($M_\infty = 6$). Minimum pressures

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[1]Myers, A. W. and Hahn, J. S. "Drag and Performance Characteristics of Flexible Aerodynamic Decelerators in the Wake of Basic and Modified Arapaho "C" Test Vehicle Configurations at Mach Numbers from 2 to 5." AEDC-TR-67-75 (AD 813808), May 1967.

range from about one-tenth to one-twentieth of the maximum pressures. A description of the tunnel and airflow calibration information may be found in the Test Facilities Handbook[2].

2.2 TEST ARTICLES

2.2.1 Forebodies and Support System

The forebodies employed for the tests are shown in Fig. 1 (Appendix). The 0.182-scale model of the Arapaho "C" (configuration 2) consisted of a blunted cone nose, cylindrical centerbody, and flared afterbody. Configuration 3 consisted of a blunted, elliptical cone with a nose shape identical to configuration 2.

The forebody support system (Fig. 1b) consisted of a strut spanning the width of the tunnel and mounted to the sidewalls. The drag tensiometer and a winch assembly for varying the location of the decelerator aft of the forebody were housed in a vacuum tank, which was also mounted to the tunnel sidewall (Fig. 1b). The decelerator support line passed through the model and strut and into the vacuum tank when it was attached to the tensiometer and winch assembly.

2.2.2 Decelerator Models

Design and construction details of the four parasonic parachutes, which are constructed in the shape assumed by an inflated hyperflo parachute (hyperflo parachutes are constructed as truncated cones) with porous and low porosity skirts, are given in Fig. 2. Construction variables investigated were canopy size and roof grid size. Constant total porosity (λ_t) of 5 percent was maintained for all parachutes by careful application to the roofs of a flexible, thermal coating. Canopy location (x/d) behind the forebodies was varied from 5 to 7.

2.3 INSTRUMENTATION

Parachute drag measurements were made with a 60-lb tensiometer located in the winch assembly and calibrated for ranges of 30 and 60 lb. Average drag values were monitored with a low response servopotentiometer, and a time history of the dynamic output from the tensiometer

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[2]Test Facilities Handbook (6th Edition). "von Kármán Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, November 1966.

was recorded on an oscillograph. The accuracy of the drag measuring system, determined from repeated static loads applied before the test, is shown below.

Load Range, lb	Error, lb
0 to 5	±0.15
6 to 15	±0.25
16 to 30	±0.33
31 to 60	±0.84

Parachute performance was monitored on two high-speed, 16-mm motion-picture cameras (one for side motion pictures and one for schlieren photography), and additional photographic results were obtained with still cameras mounted in the schlieren system and next to the test section windows.

Local wake centerline pitot and static pressures and total temperature were measured with single, low interference probes mounted to an axial probe drive mechanism (Fig. 3). The measured static and pitot pressures were then used to calculate the local Mach number and dynamic pressure. The accuracy of the calculated Mach number is estimated to be within ±0.10.

SECTION III
DECELERATOR TEST PROCEDURE

Before each test run, the parachute canopy and suspension lines were packed in a deployment bag, which was then suspended near the base of the forebody model by a pull cord routed from the rear of the bag through the tunnel sector. The pull cord was held taut during tunnel start, and when the desired test condition was established, a sharp pull on the cord removed the bag. Parachute location behind the forebody was set by the remotely operated winch assembly using reference marks placed on the tunnel windows.

SECTION IV
RESULTS AND DISCUSSION

4.1 PARACHUTE DRAG AND CENTERLINE WAKE CHARACTERISTICS

The average drag coefficients of parachutes behind forebody configuration 2 are presented in Fig. 4. The drag of parachute configuration 1 (small mesh canopy) was higher for all test conditions than the

drag of parachute configuration 2 (large mesh canopy), although the variation between the two was small for $M_\infty > 2$. The data from the present test and those reported by Myers and Hahn[3] (solid symbols) show the same trends with x/d, and except for $M_\infty = 2$ the present drag values are somewhat higher than the previous measurements.

The variation of the drag coefficients of the larger diameter parachutes (configurations 3 and 4) behind forebody 3 is presented in Fig. 5. Unlike the small diameter parachutes behind forebody 2 (Fig. 4), increasing the canopy mesh size of the large diameter parachutes (behind forebody 3) had little effect on the parachute drag for $M_\infty < 3$ and increased the drag for $M_\infty = 4$ and 5.

The variation of the local Mach number and dynamic pressure on the centerline of the wake of forebody 2 is presented in Fig. 6. Both the local Mach number and dynamic pressure increased as x/d increased, until at $x/d = 10$, these parameters were 78 and 65 percent, respectively, of the free-stream value at $M_\infty = 2$ and 66 and 43 percent of the free-stream value at $M_\infty = 5$. The sonic point location ($M_L = 1$) decreased from $x/d \approx 3.2$ at $M_\infty = 2$ to $x/d < 1.0$ at $M_\infty = 4$ and 5.

4.2 PARACHUTE PERFORMANCE

The performance of the parachutes for each test condition is summarized in Table I. The inflation characteristics of the parachutes were generally good for the x/d range investigated. The stability of the smaller diameter parachutes behind forebody 2 increased with Mach number and was independent of canopy mesh size. The stability of the large diameter parachutes behind forebody 3 was either independent of Mach number (small mesh canopy) or increased as Mach number decreased (large mesh canopy). The observations presented in the table are the results of evaluations of the photographic data. Earlier reports by the author present supplementary information on the performance of parachutes and forebodies[4, 5, 6].

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[3]Ibid, p. 1.

[4]Myers, A. W. "Aerodynamic Characteristics of Basic and Modified Arapaho "C" Test Vehicle Configurations at Mach Numbers from 2.5 to 5." AEDC-TR-66-229, December 1966.

[5]Ward, L. K., and Myers, A. W. "Free-Flight Testing of Aerodynamic Decelerators in a Supersonic Wind Tunnel." AEDC-TR-67-93 (AD815090), June 1967.

[6]Myers, A. W. "Drag and Performance Characteristics of Flexible Supersonic Decelerator Models at Mach Numbers from 2 to 6." AEDC-TR-67-224, November 1967.
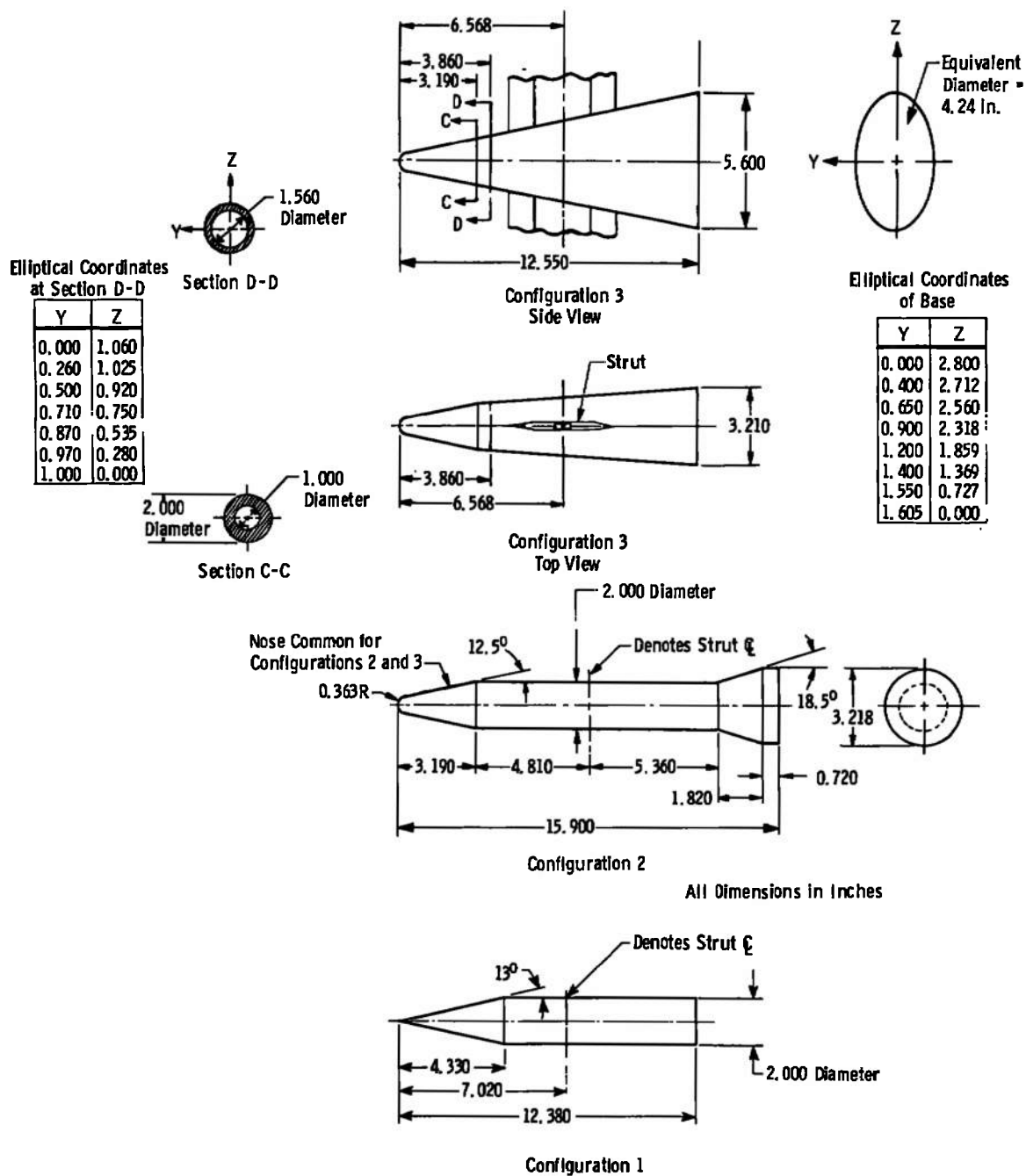
TABLE I
SUMMARY OF PARACHUTE TEST CONDITIONS AND PERFORMANCE RESULTS

Parachute Configuration	Forebody Configuration	M_∞	x/d Min	x/d Max	q_∞, psia	C_{D_P} Min	C_{D_P} Max	Remarks
1	2	2	5	7	1.0	0.85	1.04	Canopy inflation good at all x/d. Light to medium canopy pumping at x/d = 5 increasing to medium to heavy at x/d = 6 and 7. Stable to unstable at all x/d.
		3				0.45	0.57	Inflation same as M_∞ = 2. Light canopy pumping at x/d = 5 increasing to heavy at x/d = 6 and 7. Very stable at x/d = 5. Very stable to unstable at x/d = 6 and 7.
		4				0.34	0.42	Inflation same as M_∞ = 2. Light canopy pumping at all x/d. Very stable at all x/d.
		5				0.34	0.38	Same as M_∞ = 4.
2		2				0.61	0.88	Inflation good at all x/d. Canopy motionless at x/d = 5 with light pumping at x/d = 6 and 7. Very stable at x/d = 5 and 6, stable to unstable at x/d = 7.
		3				0.44	0.47	Same as M_∞ = 2 except very stable to stable at x/d = 7.
		4				0.31	0.38	Inflation same as M_∞ = 2. Canopy motionless at x/d = 5, with light pumping at x/d = 6 increasing to light to medium at x/d = 7. Very stable at x/d = 5, very stable to stable at x/d = 6 and 7.
		5				0.27	0.30	Fair inflation at x/d = 5, good inflation at x/d = 6 and 7. Medium canopy pumping at x/d = 5, light at x/d = 6, and light to medium at x/d = 7. Very stable at x/d = 5, very stable to stable at x/d = 8 and 7.
3	4	2			0.7	0.87	1.01	Very stable, well inflated, with light canopy pumping at all x/d.
		3			0.5	0.70	0.79	Same as M_∞ = 2.
		4				0.30	0.47	Same as M_∞ = 2.
		5				0.13	0.27	Good inflation at all x/d. Canopy motionless at x/d = 5, with light to medium pumping at x/d = 6 and 7. Very stable at all x/d.
4		2			0.7	0.92	1.04	Canopy well inflated with light pumping at all x/d. Very stable at x/d = 5 and 6, and stable at x/d = 7.
		3			0.5	0.62	0.80	Poor inflation at x/d = 5, with very heavy canopy pumping. Good inflation with medium to heavy canopy pumping at x/d = 6 and 7. Unstable at x/d = 5, stable at x/d = 6 and 7.
		4				0.34	0.55	Good inflation at all x/d, with medium canopy pumping. Very stable to stable at x/d = 5. Unstable at x/d = 6 and 7.
		5				0.23	0.38	Fair inflation at x/d = 5, good inflation at x/d = 6 and 7. Light canopy pumping at x/d = 5 increasing to light to medium at x/d = 6 and 7. Stable to unstable at x/d = 5 and 6, stable at x/d = 7.

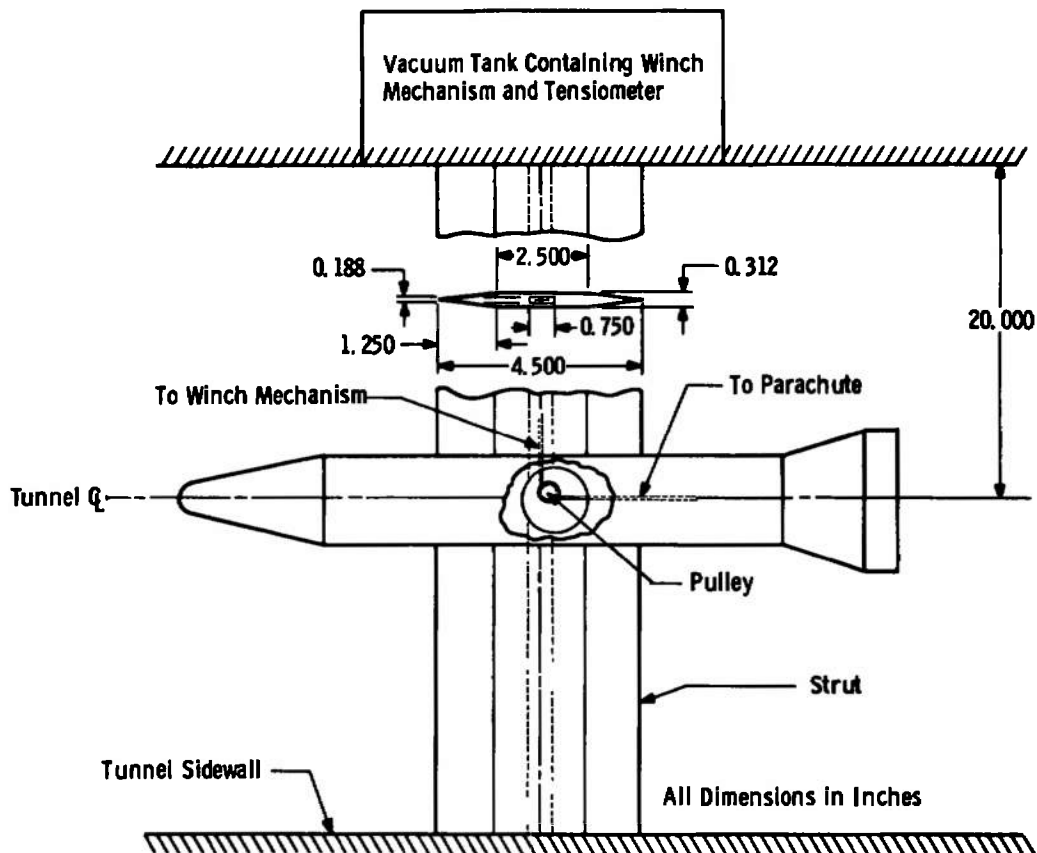Note: The following nomenclature is used in discussing parachute stability:

Very stable - Oscillations less than ±2 deg

Stable - Oscillations between ±2 and 5 deg

Unstable - Oscillations greater than ±5 deg

APPENDIX

ILLUSTRATIONS

Elliptical Coordinates at Section D-D

Y	Z
0.000	1.060
0.260	1.025
0.500	0.920
0.710	0.750
0.870	0.535
0.970	0.280
1.000	0.000

Elliptical Coordinates of Base

Y	Z
0.000	2.800
0.400	2.712
0.650	2.560
0.900	2.318
1.200	1.859
1.400	1.369
1.550	0.727
1.605	0.000

All Dimensions in Inches

a. Forebody Details

Fig. 1 Forebody and Strut Support Details

9

Vacuum Tank Containing Winch
Mechanism and Tensiometer

0.188

2.500

0.312

20.000

1.250

0.750

4.500

To Winch Mechanism

To Parachute

Tunnel ℄

Pulley

Strut

Tunnel Sidewall

All Dimensions in Inches

b. Strut Details

Tunnel Sidewall

x

Tunnel ℄

Forebody

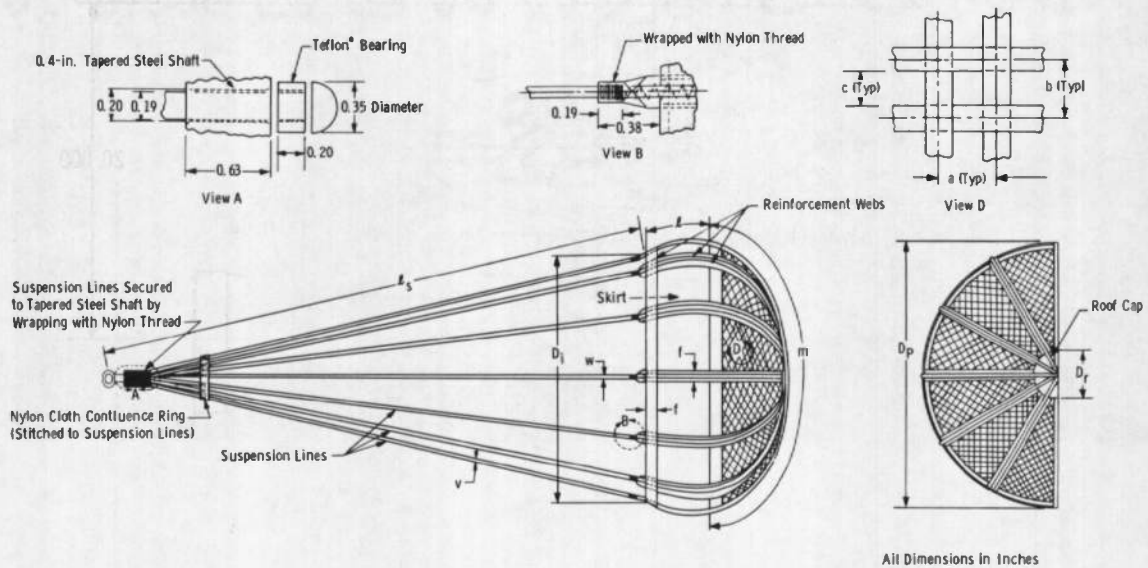Support Line
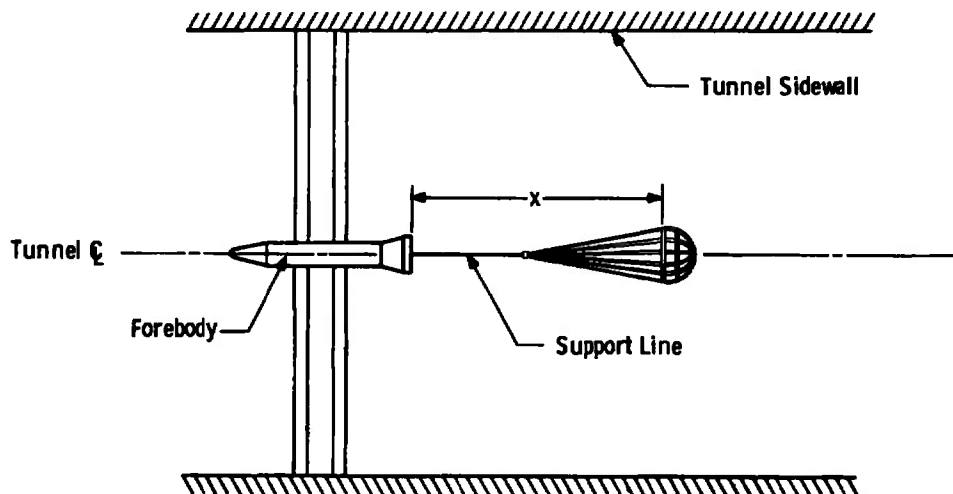
c. Tunnel Installation Sketch

Fig. 1 Concluded

a. Parasonic Parachute Construction

| Parachute Configuration	λ_t, percent	D_i, in.	D_p, in.	D_r, in.	d, in.	f, in.	v, in.	w, in.	ℓ_s, in.	Suspension Line Material	Skirt Material and Roof Cap	Roof Material	a, in.	b, in.	c, in.	Reinforcement Webs	ℓ, in.	m, in.
1	5	5.77	6.00	1.65	0.08	0.25	0.08	0.08	12.50	MIL-C-5040 Type I Cord	4787 Nylon Cloth, 0.84 oz/yd² Coated with D1596-F839 Polyurethane	HT-83-44 Nomex Mesh Cloth, 3.D1 oz/yd², Pre-Coated with D1569-F839 Polyurethane. Porosity Controlled by Coating with D-65 Flexible Thermal Coating.	0.03	0.03	0.01	Double-Fold Cotton Bias Tape, 88 by 80	1.81	6.83
2	5	5.75	6.00	1.71	0.08	0.25	0.08	0.13	12.50	Same as Parachute Configuration 1	Same as Parachute Configuration 1	MIL-T-713A, Class II, Type S Nylon Lacing, Pre-Coated on Form with D1569-F839 Polyurethane. Porosity Controlled as Above.	0.11	0.11	0.04		1.81	6.83
3	5	7.57	7.86	1.96	0.08	0.25	0.08	0.08	16.7D	MIL-C-5040 Type III Cord with Fibers Removed	Same as Parachute Configuration 1	Same as Parachute Configuration 1	0.03	0.03	0.01		2.33	8.73
4	5	7.52	7.86	2.30	0.08	0.25	0.08	0.13	17.0	Same as Parachute Configuration 3	Same as Parachute Configuration 1	Same as Parachute Configuration 2	0.11	0.11	0.04		2.33	8.73

b. Design Details

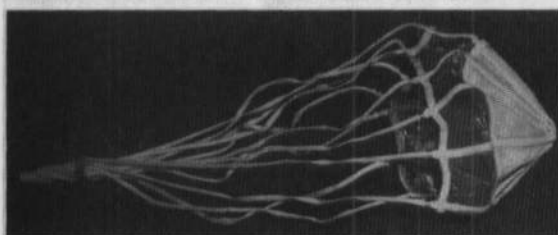Fig. 2 Decelerator Design and Construction Parameters
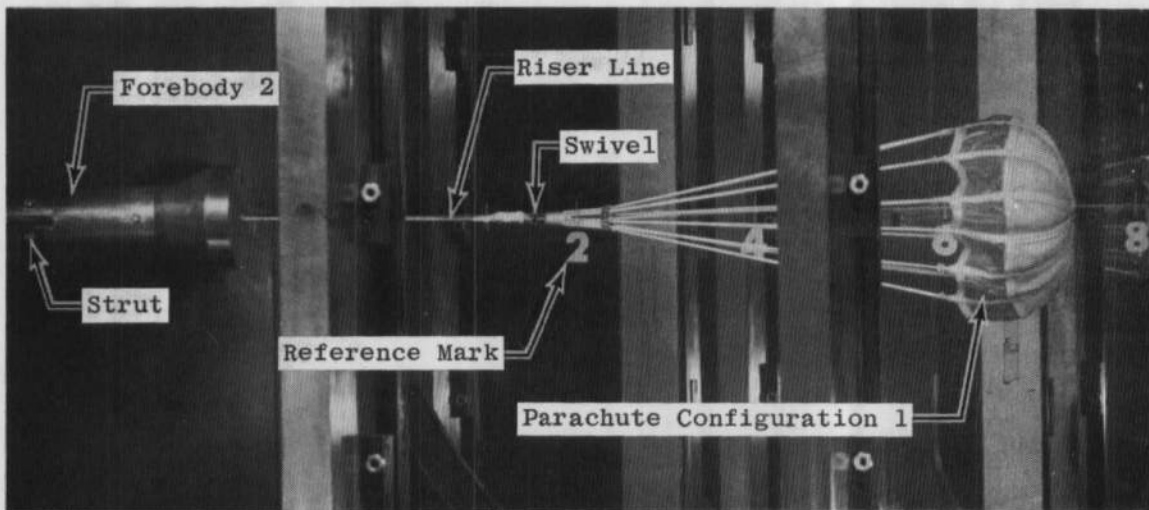
c. Configurotion 1 in Tunnel A, $M_\infty = 4$, $q_\infty = 1.0$ psio
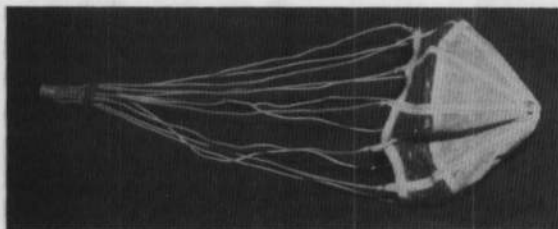
Parachute Configuration 1
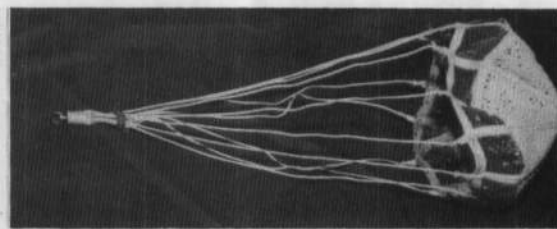
Parachute Configuration 2

Parachute Configuration 3

Parachute Configuration 4

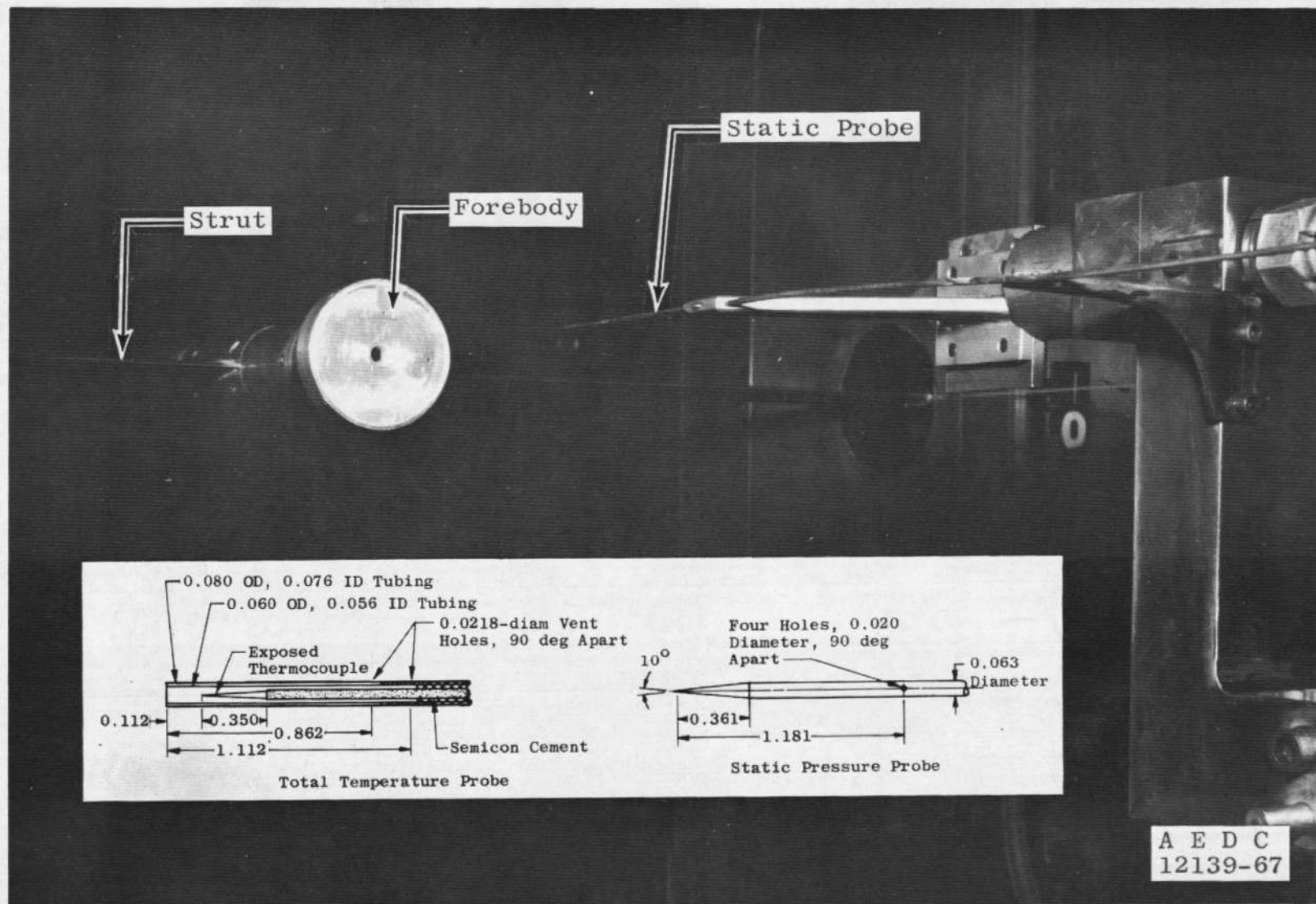d. Configuration Photogrophs
Fig. 2 Concluded

Fig. 3 Wake Survey Probe Details
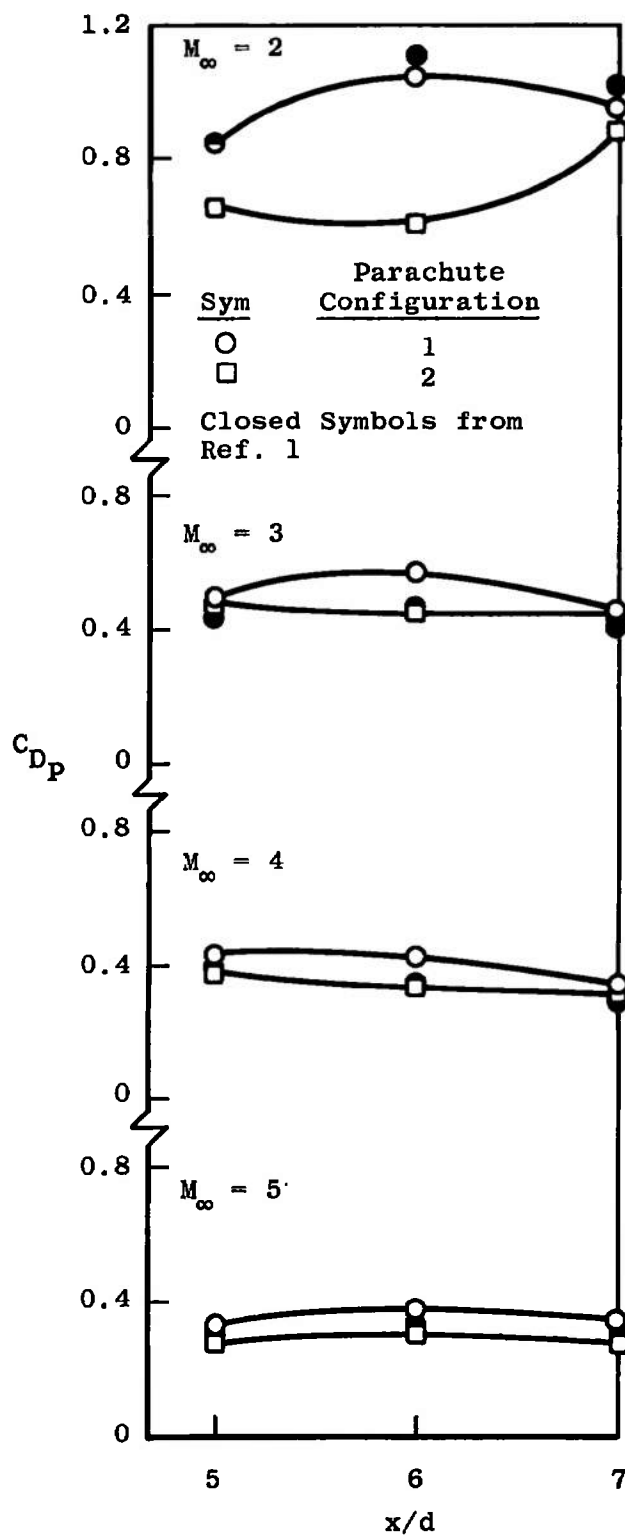
Fig. 4 Effect of Conopy Design, Location in the Wake, ond Moch Number on the Drag of Porochutes behind Forebody Configurotion 2, q_∞ = 1.0 psio
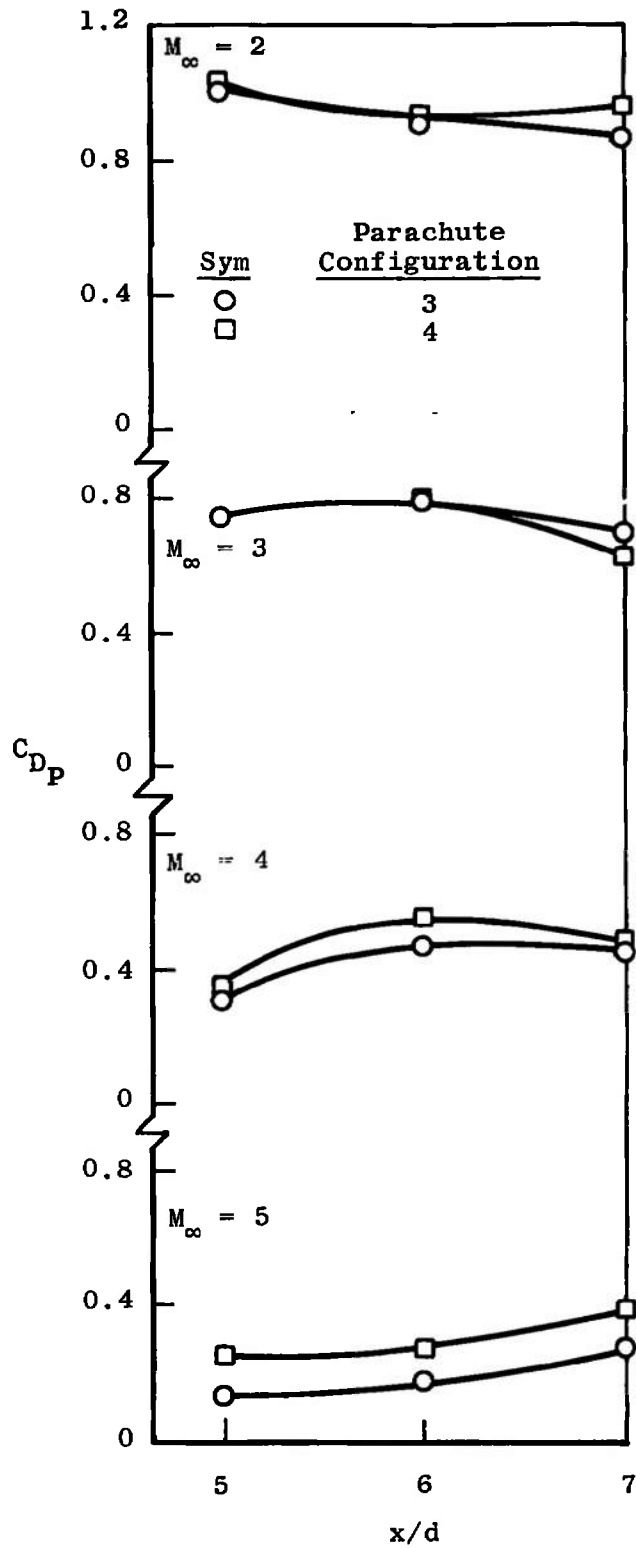
Fig. 5 Effect of Canopy Design, Locotion in the Wake, ond Mach Number on the Drag of Parachutes behind Forebody Configuration 3, $q_{\infty} = 0.5$ psio
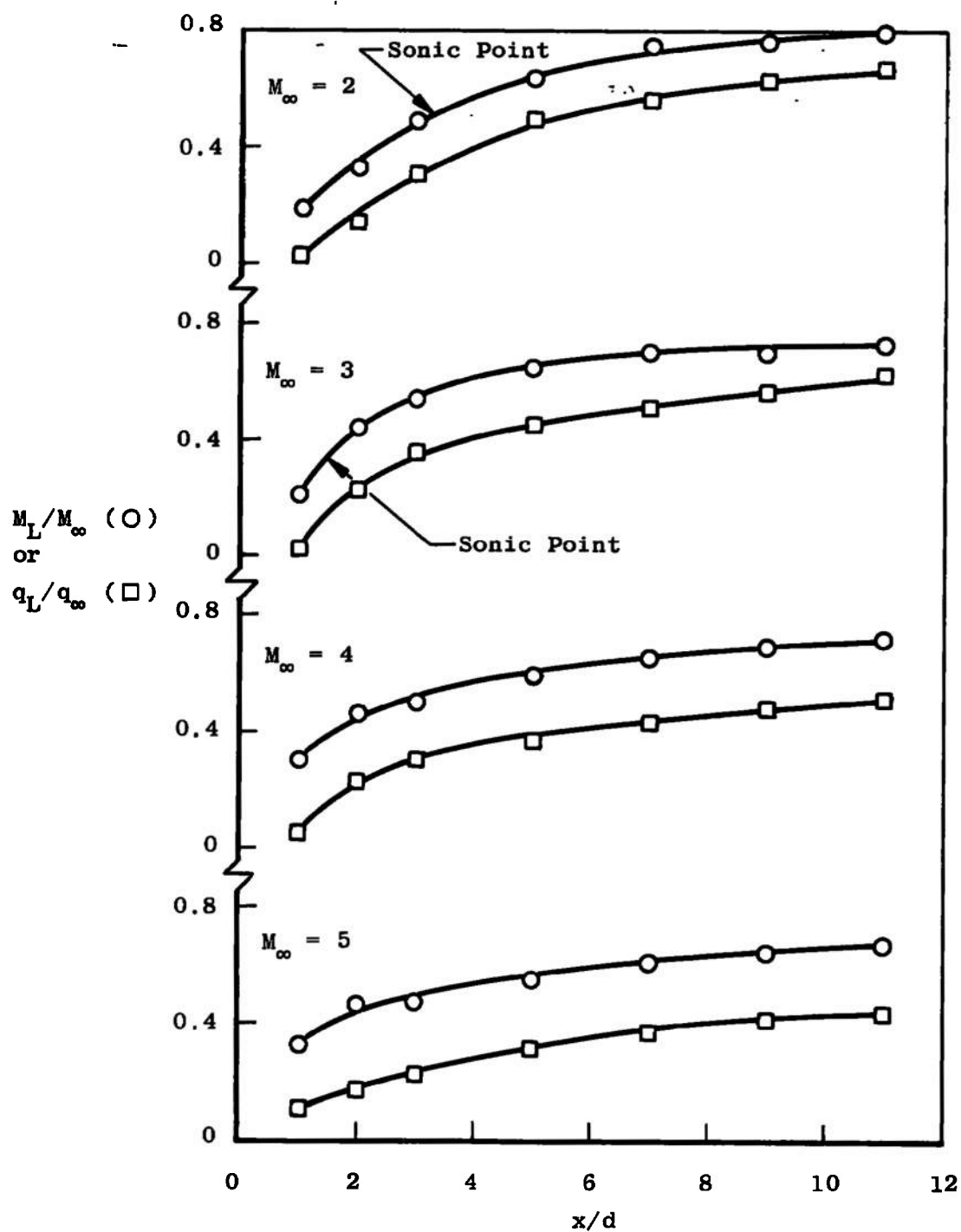
Fig. 6 Wake Centerline Characteristics of Forebody Configuration 2, $q_\infty = 1.0$ psia

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*	2a. REPORT SECURITY CLASSIFICATION
Arnold Engineering Development Center, ARO, Inc., Operating Contractor, Arnold Air Force Station, Tennessee	UNCLASSIFIED
	2b. GROUP N/A

3 REPORT TITLE:
DRAG AND PERFORMANCE CHARACTERISTICS OF FLEXIBLE AERODYNAMIC DECELERATORS IN THE WAKES OF DOUBLE-STRUT MOUNTED FOREBODIES AT MACH NUMBERS FROM 2 TO 5

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
September 12 to 16, 1967 – Final Report

5. AUTHOR(S) *(First name, middle initial, last name)*
A. W. Myers, ARO, Inc.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1967	22	5

8a. CONTRACT OR GRANT NO. AF40(600)-1200	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 6065	AEDC-TR-67-260
c. Program Element 6240533F	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d. Task 606507	N/A

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Available in DDC.	Air Force Flight Dynamics Laboratory (FDFR), Wright-Patterson AFB, Ohio

13. ABSTRACT

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
aerodynamic configurations						
flexible decelerators						
performance						
forebodies						
double-strut mounted						
supersonic flow						

2. Parachutes -- Perfor—

1-15.

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